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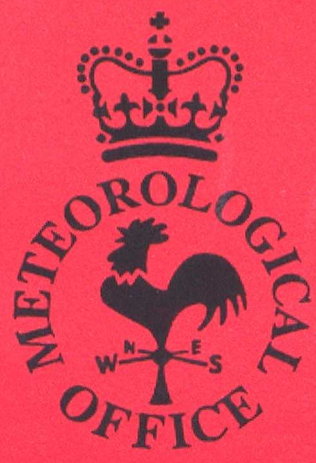

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Central Forecasting Technical Note. No. 15

Analysis of Tropical Cyclone Forecast Errors.

by S.Coulter

January. 1994

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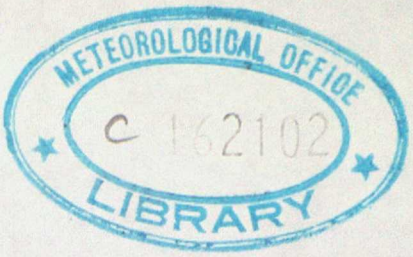


Introduction

The contents of this paper are based on a report produced by Johnny C L Chan and W K Kay in the journal ' Weather and Forecasting' (AUG. 1993).
The authors carried out a detailed evaluation of the performance of the coarse-mesh 15-level model in predicting the movement of 15 Tropical Cyclones over the North West Pacific during 1987.

The statistics produced for this study use 1992 data from verified tropical storms (i.e. those storms with an intensity greater than 31 Knots), both in the northern and southern hemisphere. The errors discussed include positional, meridional, zonal, cross track and along track. The methods used to derive these statistics are described in section 2. Polar charts are used to illustrate the change in systematic errors with forecast time.

In most cases the data are separated into six different basins(see **Fig 1.1**) : The North Indian (NI), South West Indian (SWI), North Atlantic (NAT), Australian (AUS), the North West Pacific (NWP), lying west of 180.0°E and the North East Pacific (NEP), situated east of 180.0°E.

In addition the Tropical Cyclone (TC) forecast errors are divided by storm related parameters for each hemisphere: latitude, intensity and 12 hour intensity change.

The purpose of this study is to highlight any systematic errors in the prediction of TC motion made by the UK Meteorological Office global model. It will also provide a comparison with the performance of the old 15 level model, which was operational at the time of the study by Chan and Kay in 1987.

[**N.B**. A monthly bulletin is available containing a more detailed analysis of each storm to occur during the period. The bulletin is produced by J T Heming CF5 (rm. 209a).]

2. Explanation of Errors and Conventions

The statistics referred to in this study include positional, zonal, meridional, cross track and along track errors. The observed TC positions are taken from the advisory messages issued on the Global Telecommunications System(GTS) and available in CFO.

2.1 Positional Errors

The positional error is quite simply the forecast error, defined as the shortest distance between the forecast and observed positions(see **Fig 2.1**). This error is a rough guide to how well the model has performed though provides no information of the position of the forecast in relation to the storm and therefore is no indicator of directional bias. In later text this will be referred to as the direct position error (DPE).

2.2 Zonal and Meridional (Systematic) Errors

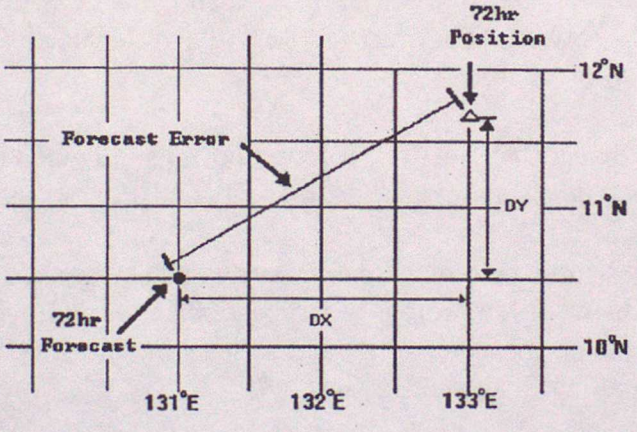


Fig 2.1

Definition of positional, zonal and meridional errors(from Chan and Kay).

The zonal error is the error in the East-West direction, while the meridional error lies in the North-South direction. These will be denoted in later text as DX (zonal) and DY (meridional), (see **Fig 2.1.**). The means of the zonal and meridional errors are known as the systematic errors. Unlike positional errors they employ a sign convention and hence are able to detect bias. A forecast position lying further polewards and to the east of the observed position results in positive values of DX and DY.

2.3 Along Track and Cross Track Errors

The positional error can be resolved along the tropical cyclone track and across the track, giving rise to along track (AT) and cross track (CT) errors. (see **Fig 2.2.**).

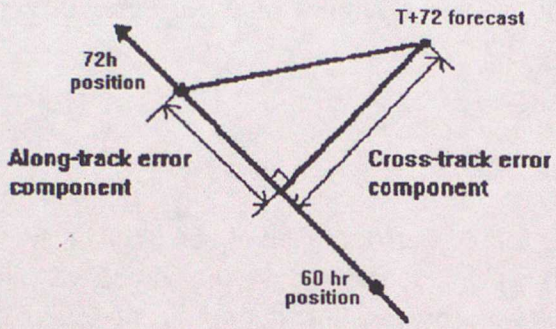


Fig 2.2.

Definition of cross track and along track errors(from Chan and Kay).

In the northern hemisphere forecast positions with the foot of the perpendicular ahead of the track and lying to the right of the track have a positive AT and CT.
In the southern hemisphere, forecast positions with a perpendicular ahead of the track and lying to the left of the track have a positive AT and CT.

In the example shown in **Fig 2.2,** the CT and AT at T+72 are calculated relative to a line connecting the observed positions valid at T+60 and T+72.
In the Northern hemisphere this forecast has a negative AT and a positive CT.

A negative AT implies the model's prediction of TC motion is too slow relative to the observed track and a positive CT may indicate an early prediction of recurvature.

A summary of error types and their conventions can be found in **Appendix A**.

2.4 The verification scheme.

The statistics presented are calculated using valid observations and forecasts, that is observations and forecasts which have passed the semi-automatic verification scheme. The criteria used in verification are: intensity must be greater than 31 Knots, relative vorticity must be greater than 0.55e-04 s^{-1}, the forecast must not lie polewards of 40° and there must be an observation within 6 hours each side of the forecast hour to verify the current forecast position. Full details of the verification scheme may be found in Hall et al 'Forecasting Tropical Cyclones and Near Surface Wind Conditions' (1993).

3. Error Statistics for the Ocean Basins.

See **Table 3.1** for the forecast errors separated by basin. The sample size of the means and standard deviations being considered are the number of valid forecasts (FC). The value of FC decreases with forecast time due to the model failing to retain a sufficient circulation or develop a circulation in the TC formation stage.

Only data with sample sizes of 10 or more forecasts for each forecast time should be taken into consideration. Numbers in brackets in **Table 3.1** correspond to AT/CT sample sizes; these are always smaller as TCs beginning with a valid observation have no observation 12 hours previous and cannot be used to generate AT/CT errors although results for DPE, DX and DY errors may still be obtained.

The data in **Table 3.1** for basins NWP, NEP, NAT and NI show a trend of negative mean AT and small but positive mean CT. This implies that for the northern hemisphere there is a tendency for the model to predict a slow TC motion with a slight over-prediction of recurvature. However it must be noted that standard deviations for these means are very large making it difficult to be certain of any overall bias.

In the northern hemisphere the systematic errors(means of DX and DY) are more varied between basins. All northern basins show large positive DX errors suggesting forecast positions too far to the east. The DY errors are more random and far smaller in magnitude. The DY standard deviations are also relatively small and combined they indicate no bias in the meridional direction.

In the southern hemisphere the results are far more inconclusive. The spread of data is larger and this is reflected in the random nature of the mean statistics. A comparison of DPE with basin(see **Fig 3.1**) shows the SWI and AUS basins to have the largest errors, this is probably due to fewer observations in the southern hemisphere leading to poorer forecasts.

3.1. Polar Plots of TC Systematic Errors.

A useful representation of systematic errors is the polar diagram. The systematic errors may be used as Cartesian co-ordinates to produce scatter diagrams. Their convention allows the scatter plots to display directional bias easily. The circles are an indicator of the direct positional error. See Polar charts (**Figs 3.1.1 to 3.1.6**).

Each data point on the polar diagrams is produced by taking the systematic errors at T+0, T+24, T+48 and T+72, for each storm with an intensity greater than 50 Kt, occurring in the basin. Each data point represents a mean value for a particular storm and forecast time. Only means with sample sizes of five or more are represented in the diagrams.

3.1.1 North East Pacific

See **Fig 3.1.1.**
The forecast errors appear to lie in all directions with a tighter distribution in the north-south plane.

3.1.2 South West Indian

See **Fig 3.1.2.**
In contrast to the NEP the larger errors tend to lie more north easterly.

3.1.3 Australian

See **Fig 3.1.3.**
The results show no definite bias.

3.1.4 North Atlantic

See **Fig 3.1.4.**
A small sample of data showing low forecast errors. The errors lie slightly more to the east but with so few data points it is difficult to ascertain if there is any overall directional bias.

3.1.5 North Indian

See **Fig 3.1.5.**
Larger errors lie to the south east and occur at T+24 onwards. The T+0 errors show a random pattern.

3.1.6 North West Pacific

See **Fig 3.1.6.**
The errors appear to be completely random.

4. Error Statistics Sub Divided by Storm Related Parameters

Systematic errors were used in the following analysis to demonstrate possible differences in errors with respect to the TC location and strength. See **Tables 4.1, 4.2 and 4.3.**
The parameters are based on the verified TC positions **not** the forecast positions.

4.1 Latitude

The errors for the basins NWP and NEP are divided into Southern TCs, south of 15.0° N, Central TCs (between 15.0°N and 20.0°N) and Northern (north of 20.0°N). Analysis of this kind on any other basin would lead to small samples, greatly reducing the validity of the statistics. In the paper produced by Chan and Kay the boundaries for dividing the errors were chosen to produce terciles. This is not the case in this analysis, the boundaries were chosen for convenience.

In the NWP basin large zonal errors, DX, occur in southern and central TCs with better results in northern TCs. However meridional errors (DY) are much larger in the Northern band. The sample size is greater north of 20.0°N indicating most TCs occur in this latitude band. The large sample of T+120 forecasts for this band probably indicates the TCs are more developed north of 20.0°N. (See **Table 4.1.1.).**

In the NEP basin large zonal errors, DX, are more noticeable in southern and northern TCs and T+96 onwards in central TCs. Most TCs occur in the middle band 15° - 20° N, with a greatly increased sample. The large sample shows no added variability in the data which highlights the weaker DX bias for T+48 and T+72 forecasts in the central band. (See **Table 4.1.2.).**

4.2 Intensity

These errors are divided by intensity at T+0 of the TC for each hemisphere: Weak TCs (<60 Kt), Medium TCs (60-90 Kt.), and Intense TCs (>90 Kt).

There is no obvious difference in errors for TCs with different intensities at T+0 in the northern hemisphere. The large bias to the east, suggested by the large positive values of DX, occurs equally for each division. (See **Table 4.2.1.).** Comparing meridional errors(DY) with intensity for each forecast time up to T+72, shows a tendency for weaker TCs to be forecast too far south.

In the southern hemisphere the DX error changes from negative to positive as intensity increases. (See **Table 4.2.2.).**

4.3 12 hour Intensity change

The difference in intensity of a TC with the previous 12 hour observation is known as the 12 hour intensity change (12 hr IC).
The errors divided by hemisphere and 12 hr IC are defined as follows : Weakening (IC< 0 Knots), Intensifying (IC between 0 and 10 Knots) and Rapidly Intensifying (IC> 10 Knots).

Statistics for the northern hemisphere show large zonal errors which are not significantly different across the 12hr IC divisions but the meridional errors tend to be negative for weakening TCs. (See **Table 4.3.1.).** In the southern hemisphere the sample size is much smaller, and it is difficult to extract any trends in the data. (See **Table 4.3.2.).**

The sample size at T+96 and T+120 is largest for weakening TCs. This reflects the fact that TCs present in the latter stages of the model forecast are more likely to be past peak intensity and in the weakening phase.

5. Summary

The statistics presented in this paper involve data with a large range of values making it impossible to be certain of persistent errors. When considering the data it should be remembered that 68.3% of the data lies within one standard deviation either side of the mean. Data with small means and large standard deviations should not be considered when determining if bias exists.

The main conclusions are :

- The slow bias and over prediction of recurvature in the northern hemisphere.
- The large positive zonal errors(i.e. the predictions are too far east) are more prominent in the southern and central regions of the northern hemisphere.
- TC forecast errors tend to have larger components and greater variability in the E-W direction.
- Trends in data for the southern hemisphere are difficult to determine due to the small sample and relatively large random errors present.

6. References

Chan J. C. L. and Kay W. K., 1993: ' Performance of the UK Meteorological Office global model in predicting the movement of Tropical Cyclones'. Weather and forecasting, August 1993.

Cox D. R. and Snell E. J., 1981: 'Applied statistics principles and examples'. Chapman and Hall.

Hall C. D., Hunt J. C. R., Radford A. M., Carruthers D. J. and Weng W. S., 1993: 'Forecasting Tropical Cyclones and Near Surface Wind Conditions'.

Heming J. T., 1991: 'An automated scheme for the verification of the unified model - forecast positions of Tropical Cyclones'. Not published.

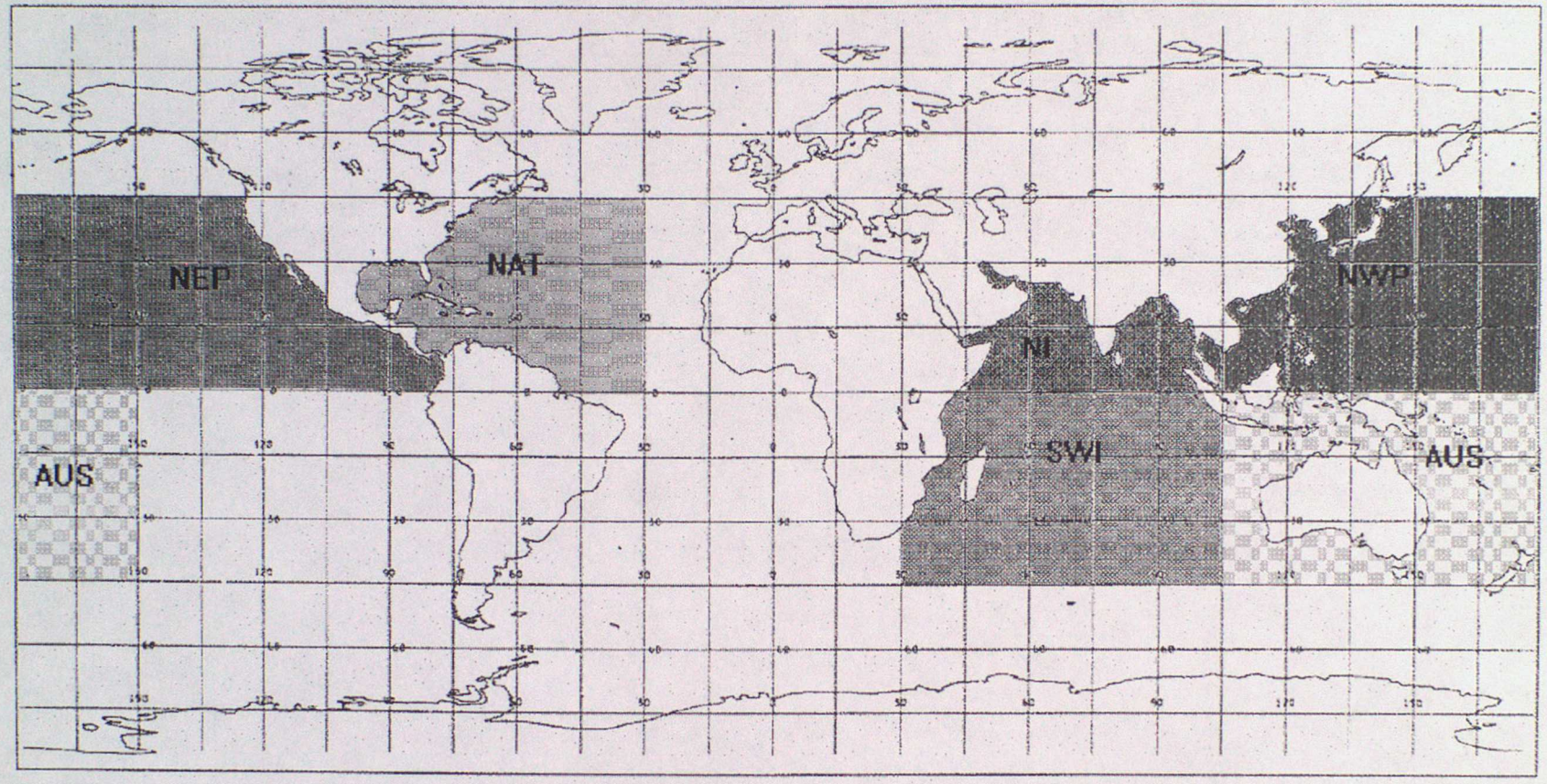


Fig 1.1

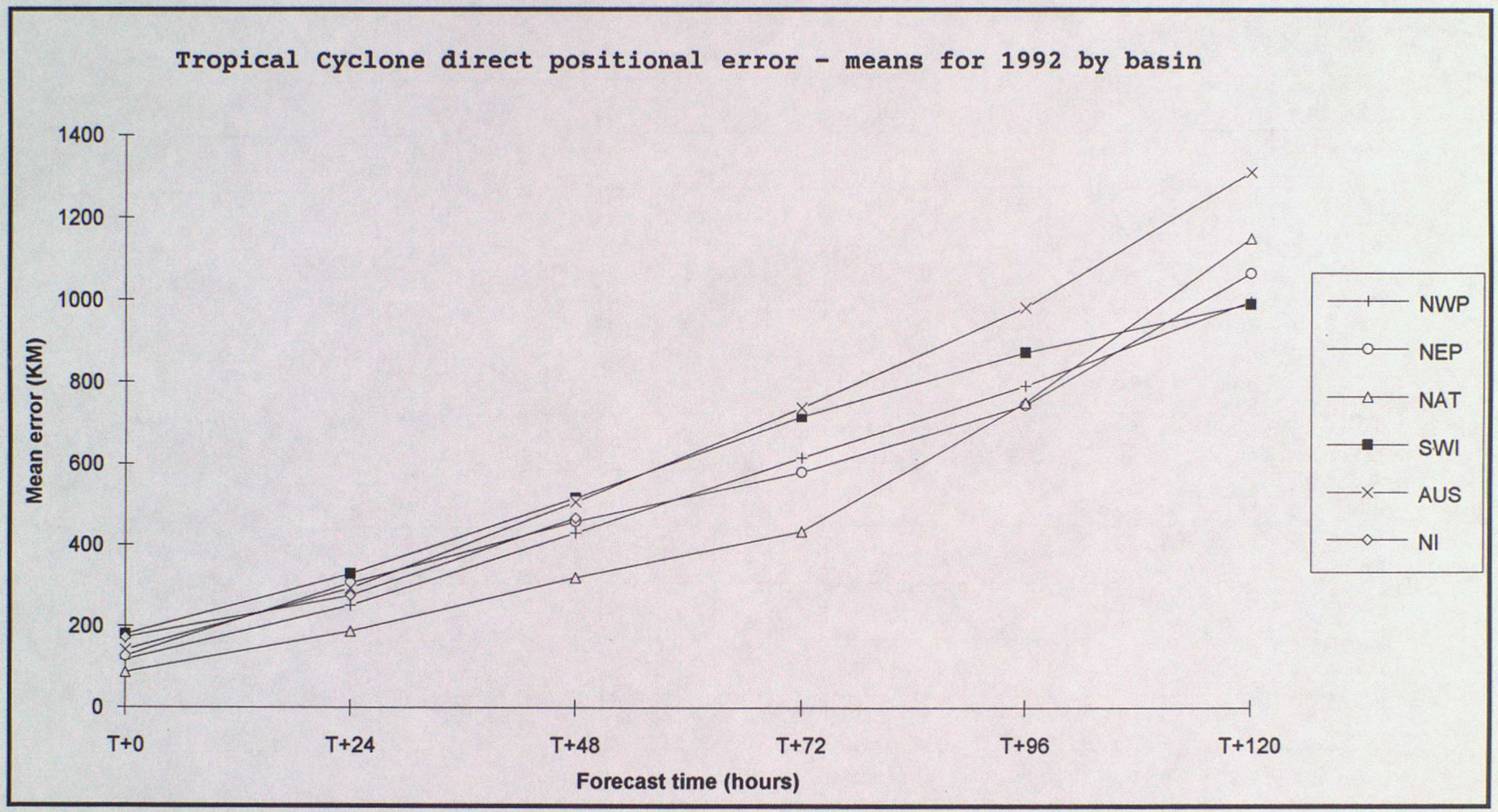

Tropical Cyclone direct positional error - means for 1992 by basin
Mean error (KM)
1400
1200
1000
800
600
400
200
0
T+0
T+24
T+48
T+72
T+96
T+120
Forecast time (hours)
NWP
NEP
NAT
SWI
AUS
NI

Fig 3.1

TABLE 3.1.

Tropical cyclone results 1992
Errors divided into basins

SWI basin
Total number of cyclones : 12

	T+0	T+24	T+48	T+72	T+96	T+120
Not FC	21	43	56	65	74	76
FC	71(58)	49	36	27	18	16
Mean DPE	180	328	516	715	872	990
Mean DX	42	37	31	112	335	360
Mean DY	-18	-74	-219	-290	-166	49
Mean AT	-108	-132	-227	-337	-467	-485
Mean CT	10	-38	-125	-128	-54	59
SD DPE	127	189	372	530	561	532
SD DX	175	298	498	658	727	820
SD DY	127	224	338	528	668	720
SD AT	133	270	538	742	840	855
SD CT	136	229	252	353	422	583

AUS basin
Total number of cyclones : 12

	T+0	T+24	T+48	T+72	T+96	T+120
Not FC	14	45	70	93	109	123
FC	152(137)	121	96	73	57	43
Mean DPE	142	293	506	737	981	1311
Mean DX	-12	-2	-28	-56	-28	40
Mean DY	-29	-57	-38	-9	140	227
Mean AT	-34	-97	-150	-157	-133	-176
Mean CT	-8	-25	-43	1	26	279
SD DPE	96	164	317	401	551	731
SD DX	128	269	484	682	995	1365
SD DY	110	192	349	493	521	614
SD AT	131	248	491	743	964	1164
SD CT	103	198	274	380	593	920

Figures in brackets represent number of forecasts available to calculate AT/CT errors.
All errors are measured in KM.

TABLE 3.1.

Tropical cyclone results 1992
Errors divided into basins

NWP basin
Total number of cyclones : 31

	T+0	T+24	T+48	T+72	T+96	T+120
Not FC	10	83	153	212	258	305
FC	387(353)	314	244	185	139	92
Mean DPE	117	251	429	615	790	996
Mean DX	36	77	132	219	265	434
Mean DY	23	27	-14	-83	-110	-108
Mean AT	-29	-78	-185	-347	-455	-430
Mean CT	33	26	25	86	189	272
SD DPE	78	166	299	438	518	635
SD DX	98	198	366	546	727	881
SD DY	90	211	348	467	533	652
SD AT	91	203	336	523	606	797
SD CT	95	206	354	410	532	712

NEP basin
Total number of cyclones : 27

	T+0	T+24	T+48	T+72	T+96	T+120
Not FC	5	91	170	224	263	276
FC	302(268)	216	137	83	44	31
Mean DPE	126	306	457	579	743	1065
Mean DX	65	140	225	263	486	787
Mean DY	18	47	35	51	-12	-135
Mean AT	-70	-154	-193	-218	-461	-654
Mean CT	43	74	83	89	36	27
SD DPE	87	183	237	286	380	508
SD DX	103	268	389	512	587	780
SD DY	92	184	251	294	350	402
SD AT	85	253	390	525	532	756
SD CT	95	184	263	288	463	642

Figures in brackets represent number of forecasts available to calculate AT/CT errors.
All errors are measured in KM.

TABLE 3.1.

Tropical cyclone results 1992
Errors divided into basins

NAT basin
Total number of cyclones : 7

	T+0	T+24	T+48	T+72	T+96	T+120
Not FC	0	24	50	58	68	73
FC	78(70)	54	28	20	10	5
Mean DPE	87	187	319	433	749	1151
Mean DX	29	101	192	212	-5	-146
Mean DY	3	-16	-47	-50	-98	-255
Mean AT	-20	-97	-234	-343	-659	-739
Mean CT	3	22	72	114	173	413
SD DPE	72	117	203	314	410	462
SD DX	85	160	288	472	869	1309
SD DY	68	112	149	154	159	200
SD AT	84	168	253	353	427	733
SD CT	77	103	146	141	343	659

NI basin
Total number of cyclones : 10

	T+0	T+24	T+48	T+72	T+96	T+120
Not FC	0	29	41	50	54	57
FC	60(47)	31	19	10	6	3
Mean DPE	172	275	466	728	572	1126
Mean DX	65	160	261	563	2	-618
Mean DY	-11	-7	-94	-244	-240	-567
Mean AT	-79	-164	-350	-510	-229	-887
Mean CT	45	83	-1	387	-177	-352
SD DPE	109	157	240	395	170	560
SD DX	158	218	400	506	521	959
SD DY	113	172	218	282	284	475
SD AT	151	217	321	404	416	539
SD CT	99	150	265	521	382	744

Figures in brackets represent number of forecasts available to calculate AT/CT errors.
All errors are measured in KM.

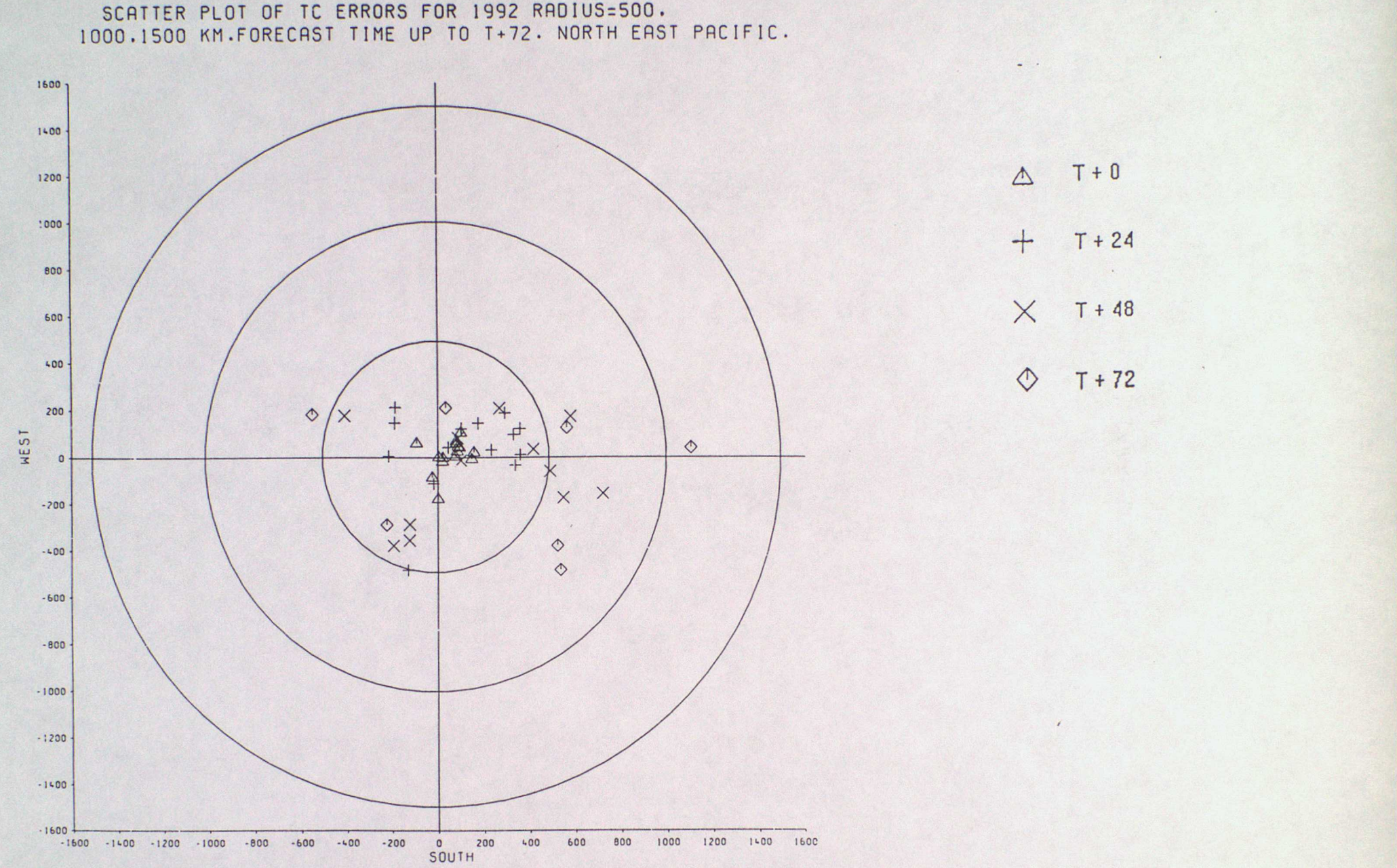

SCATTER PLOT OF TC ERRORS FOR 1992 RADIUS=500.
1000.1500 KM.FORECAST TIME UP TO T+72. NORTH EAST PACIFIC.
WEST
SOUTH
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
T + 0
T + 24
T + 48
T + 72

Fig 3.1.1

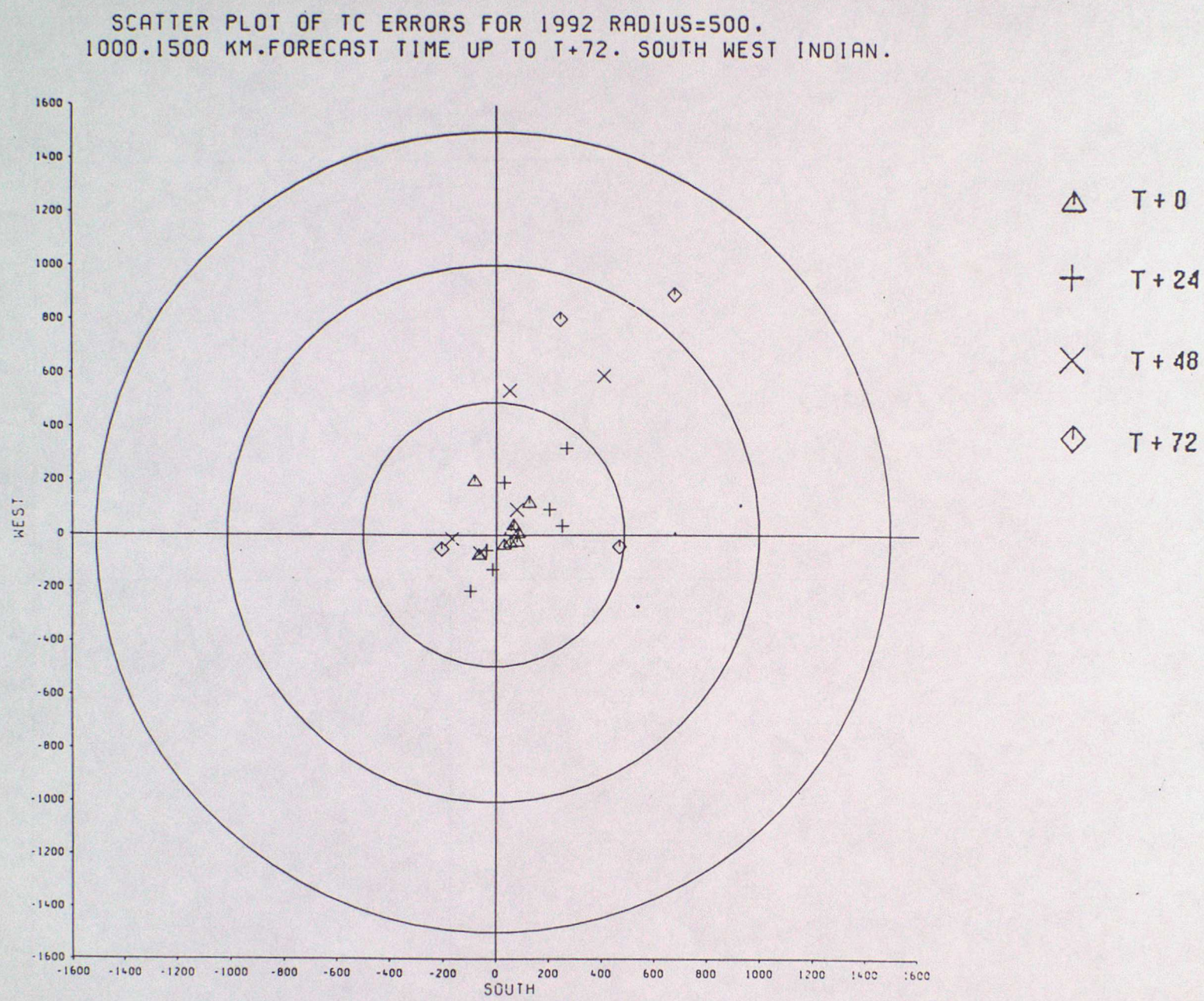

SCATTER PLOT OF TC ERRORS FOR 1992 RADIUS=500.
1000.1500 KM.FORECAST TIME UP TO T+72. SOUTH WEST INDIAN.
WEST
SOUTH
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
T + 0
T + 24
T + 48
T + 72

Fig 3.1.2

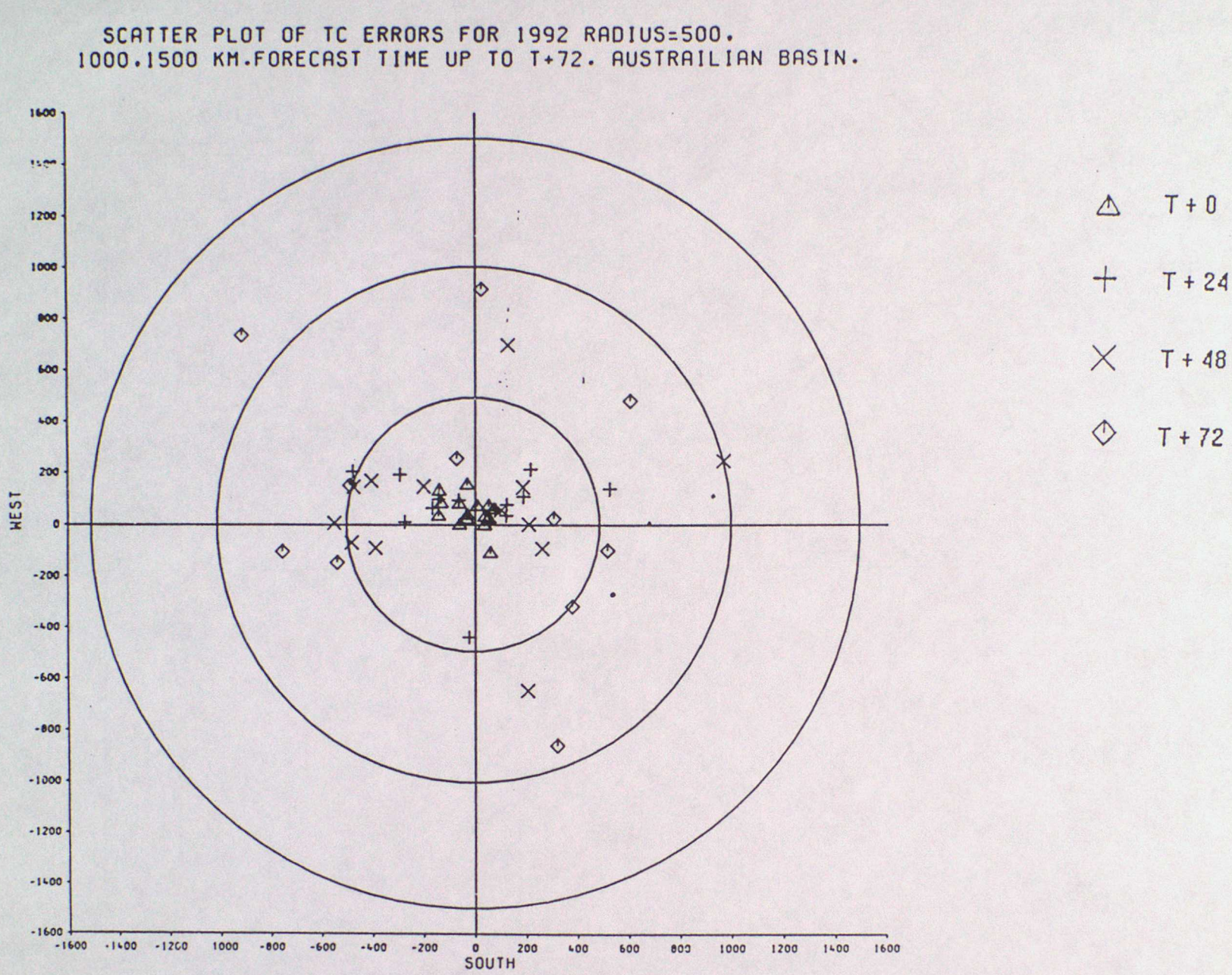

SCATTER PLOT OF TC ERRORS FOR 1992 RADIUS=500.
1000.1500 KM.FORECAST TIME UP TO T+72. AUSTRAILIAN BASIN.
WEST
SOUTH
1600
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
T + 0
T + 24
T + 48
T + 72

Fig 3.1.3

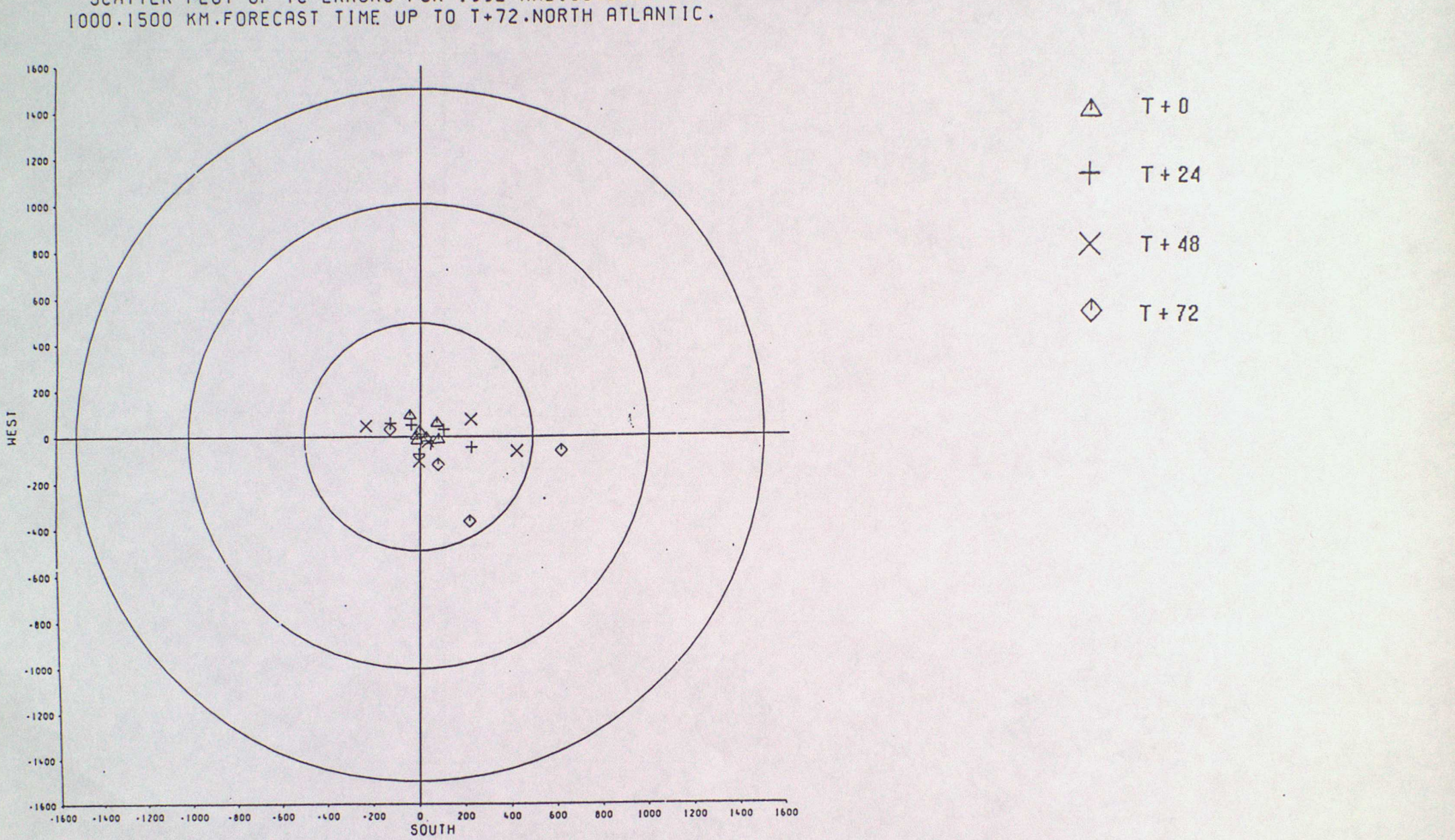
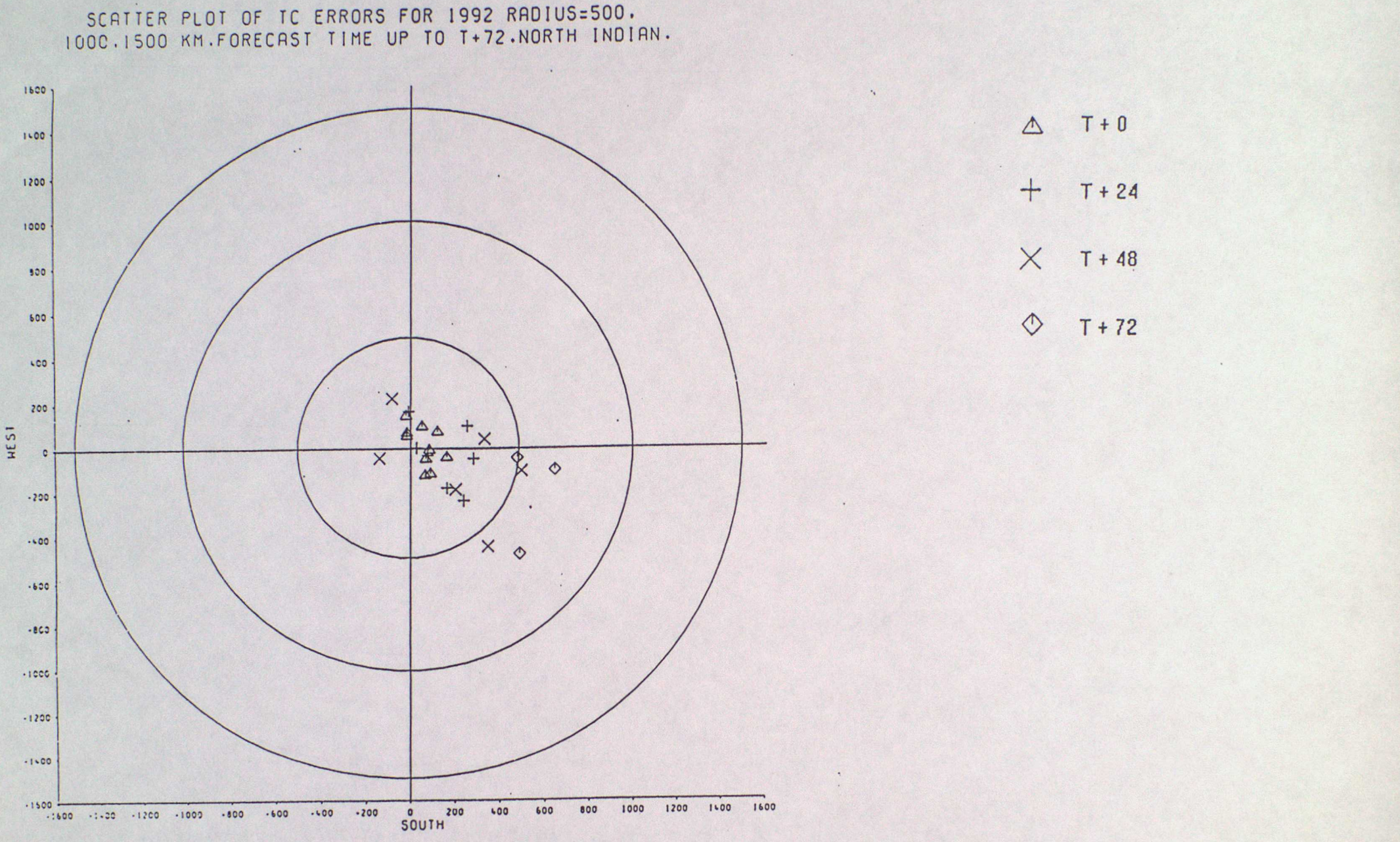

SCATTER PLOT OF TC ERRORS FOR 1992 RADIUS=500.
1000.1500 KM.FORECAST TIME UP TO T+72.NORTH ATLANTIC.
T + 0
T + 24
T + 48
T + 72
WEST
SOUTH
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600

Fig 3.1.4


SCATTER PLOT OF TC ERRORS FOR 1992 RADIUS=500.
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WEST
SOUTH
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1200
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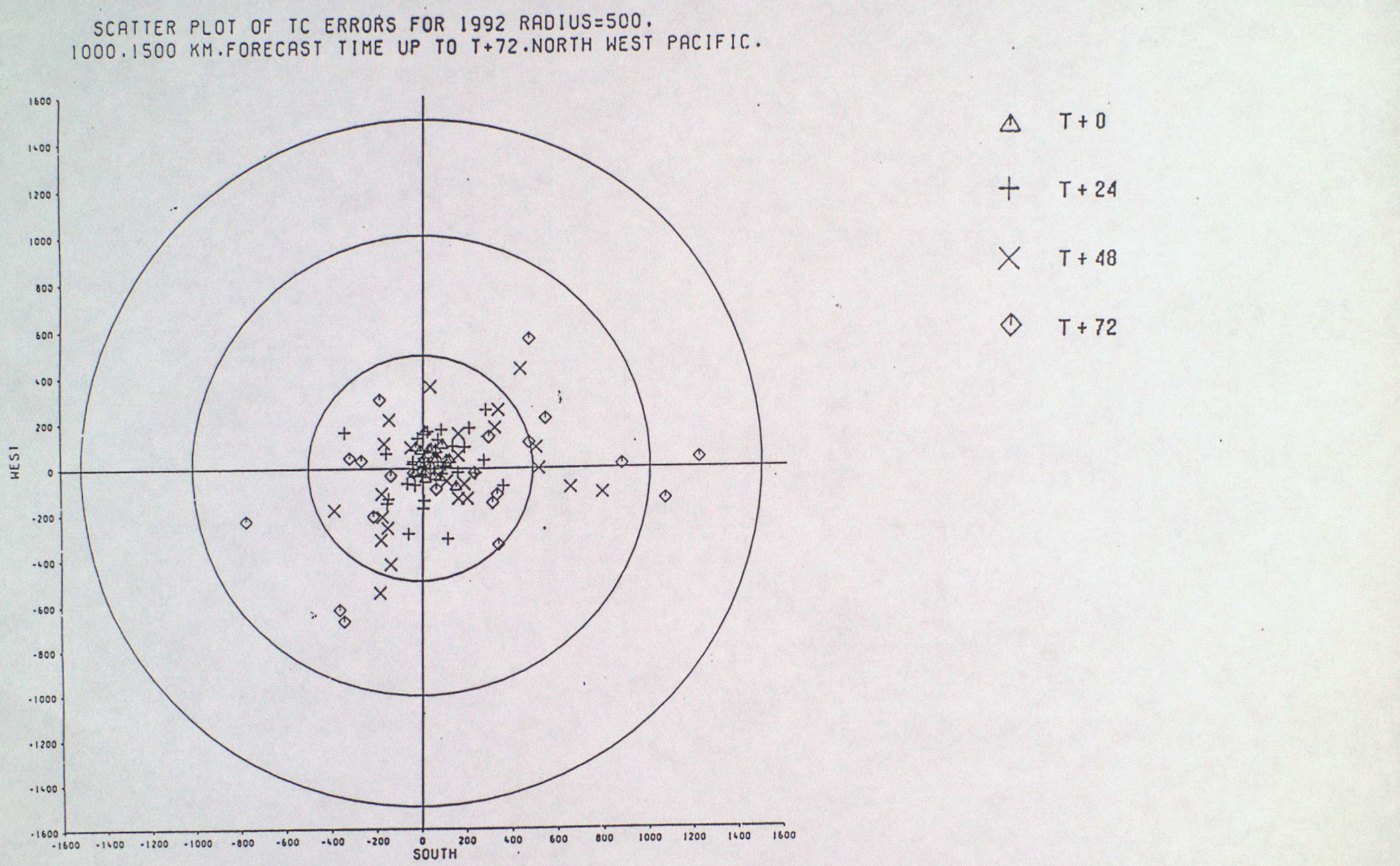
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
T + 0
T + 24
T + 48
T + 72

Fig 3.1.5


SCATTER PLOT OF TC ERRORS FOR 1992 RADIUS=500.
1000.1500 KM.FORECAST TIME UP TO T+72.NORTH WEST PACIFIC.
WEST
SOUTH
1600
1400
1200
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800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
T + 0
T + 24
T + 48
T + 72

Fig 3.1.6

TABLE 4.1
Errors separated by latitude band

For the north west pacific only.

MEAN SYSTEMATIC ERRORS, DX, DY
AS SEPARATED BY LATITUDE BAND
1992 STATISTICS
Table 4.1.1

FCTIME	FCAST	SOUTHERN TCS < 15.0N	FCAST	CENTRAL TCS 15.0 - 20.0N	FCAST	NORTHERN TCS > 20.0N	
0	133	58 (94)	107	40 (88)	157	13 (104)	DX
		32 (88)		23 (94)		13 (96)	DY
24	96	171 (178)	87	48 (234)	138	18 (165)	DX
		74 (166)		-9 (176)		12 (250)	DY
48	67	330 (324)	66	123 (354)	118	-7 (356)	DX
		81 (266)		7 (248)		-94 (411)	DY
72	51	527 (484)	40	233 (561)	101	-11 (525)	DX
		59 (388)		93 (402)		-233 (471)	DY
96	35	619 (643)	25	400 (373)	80	46 (795)	DX
		68 (412)		250 (562)		-304 (485)	DY
120	20	781 (490)	17	476 (401)	55	295 (1054)	DX
		-21 (386)		525 (603)		-335 (612)	DY

For the north east pacific only.

MEAN SYSTEMATIC ERRORS, DX, DY
AS SEPARATED BY LATITUDE BAND
1992 STATISTICS
Table 4.1.2

FCTIME	FCAST	SOUTHERN TCS < 15.0N	FCAST	CENTRAL TCS 15.0 - 20.0N	FCAST	NORTHERN TCS > 20.0N	
0	95	75 (110)	154	64 (106)	53	48 (80)	DX
		34 (73)		11 (107)		10 (73)	DY
24	57	169 (311)	118	137 (266)	41	112 (200)	DX
		115 (144)		48 (176)		-52 (215)	DY
48	36	345 (430)	80	156 (379)	21	284 (299)	DX
		92 (241)		68 (222)		-193 (262)	DY
72	21	492 (575)	48	142 (508)	14	334 (261)	DX
		-62 (305)		151 (213)		-122 (386)	DY
96	12	487 (499)	25	475 (681)	7	524 (399)	DX
		-177 (475)		48 (288)		59 (234)	DY
120	8	894 (388)	20	727 (944)	3	908 (163)	DX
		-372 (553)		-51 (311)		-66 (363)	DY

Standard deviations are given in the parentheses.
All errors are measured in KM.

TABLE 4.2
Errors separated by intensity

For the northern hemisphere only.

MEAN SYSTEMATIC ERRORS, DX, DY
AS SEPARATED BY INTENSITY
1992 STATISTICS
Table 4.2.1

FCTIME	FCAST	WEAK TCS < 60 KT	FCAST	MEDIUM TCS 60 - 90 KT	FCAST	INTENSE TCS > 90 KT	
0	406	55 (113)	279	38 (103)	142	47 (83)	DX
		11 (89)		22 (94)		24 (93)	DY
24	228	129 (225)	243	98 (242)	144	82 (191)	DX
		14 (182)		33 (189)		43 (218)	DY
48	124	217 (384)	168	187 (390)	136	111 (333)	DX
		-55 (266)		20 (287)		13 (355)	DY
72	75	310 (563)	108	215 (593)	115	223 (444)	DX
		-117 (338)		-51 (411)		-1 (446)	DY
96	49	180 (785)	66	222 (746)	84	414 (613)	DX
		-227 (441)		-201 (440)		74 (486)	DY
120	29	175 (1128)	44	505 (833)	58	594 (809)	DX
		-535 (546)		-298 (423)		200 (538)	DY

For the southern hemisphere only.

MEAN SYSTEMATIC ERRORS,DX,DY
AS SEPARATED BY INTENSITY
1992 STATISTICS
Table 4.2.2

FCTIME	FCAST	WEAK TCS < 60 KT	FCAST	MEDIUM TCS 60 - 90 KT	FCAST	INTENSE TCS > 90 KT	
0	112	-8 (160)	67	6 (128)	44	35 (135)	DX
		-11 (131)		-35 (101)		-46 (90)	DY
24	66	-35 (295)	63	16 (225)	41	71 (315)	DX
		-20 (208)		-97 (199)		-74 (187)	DY
48	47	-114 (465)	49	9 (379)	36	92 (615)	DX
		-107 (386)		-120 (304)		-17 (375)	DY
72	32	-183 (678)	42	58 (541)	26	90 (840)	DX
		-220 (632)		-132 (347)		157 (522)	DY
96	23	-96 (987)	36	61 (979)	16	277 (813)	DX
		-105 (615)		6 (466)		450 (577)	DY
120	19	28 (862)	34	130 (1356)	6	420 (969)	DX
		-176 (544)		249 (598)		901 (481)	DY

Standard deviations are given in the parentheses.
All errors are measured in KM.

TABLE 4.3
Errors separated by intensity change

For the northern hemisphere only.

MEAN SYSTEMATIC ERRORS, DX, DY
AS SEPARATED BY INTENSITY CHANGE
1992 STATISTICS
Table 4.3.1

FCTIME	FCAST	WEAKENING TCS < 0 KT		FCAST	INTENSIFYING TCS 0 - 10 KT		FCAST	RAPIDLY INT. TCS > 10 KT		
0	288	41	(103)	336	50	(108)	106	59	(91)	DX
		13	(99)		20	(85)		17	(76)	DY
24	228	102	(193)	224	110	(217)	68	55	(267)	DX
		45	(223)		20	(167)		22	(172)	DY
48	172	145	(371)	138	207	(322)	36	122	(415)	DX
		-27	(371)		32	(243)		1	(330)	DY
72	138	181	(549)	83	302	(438)	17	322	(475)	DX
		-104	(439)		56	(319)		133	(316)	DY
96	95	231	(725)	48	310	(568)	10	392	(344)	DX
		-187	(498)		59	(454)		220	(480)	DY
120	64	430	(868)	29	387	(735)	3	241	(429)	DX
		-188	(569)		77	(596)		197	(351)	DY

For the southern hemisphere only.

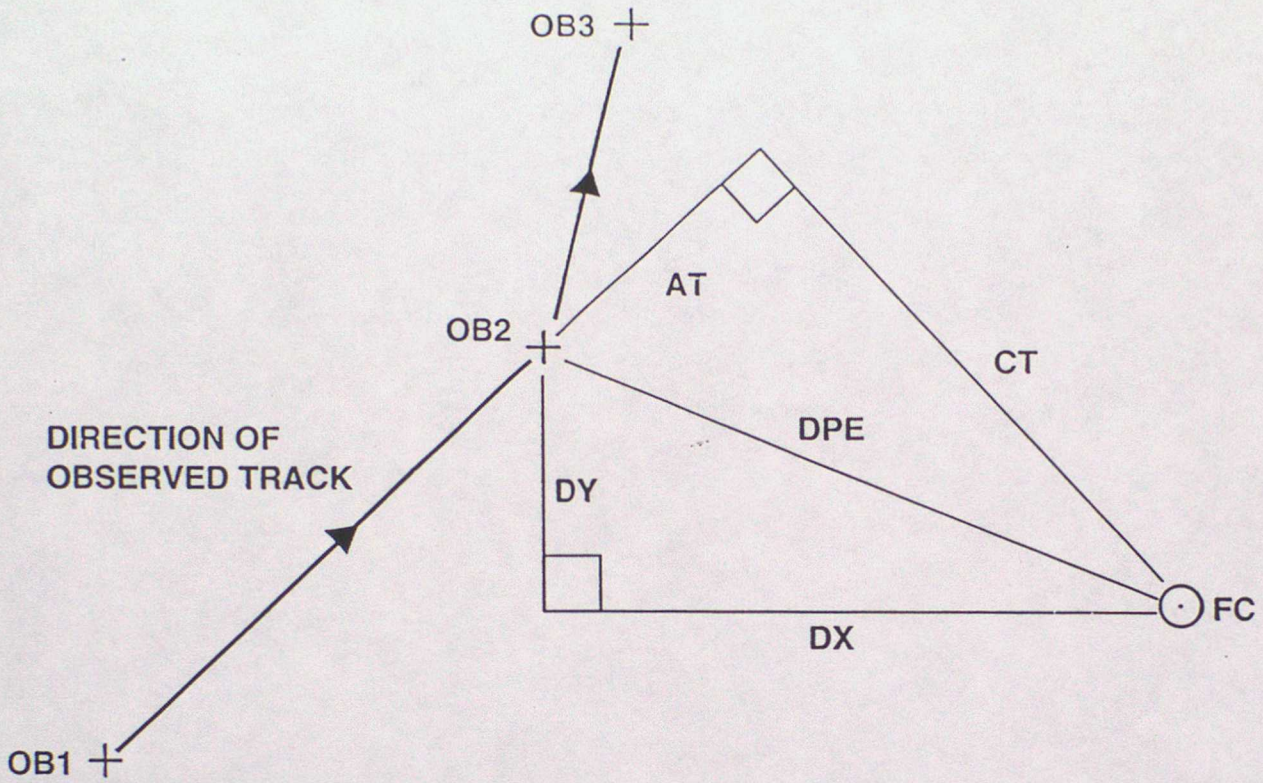
MEAN SYSTEMATIC ERRORS, DX, DY
AS SEPARATED BY INTENSITY CHANGE
1992 STATISTICS
Table 4.3.2

FCTIME	FCAST	WEAKENING TCS < 0 KT		FCAST	INTENSIFYING TCS 0 - 10 KT		FCAST	RAPIDLY INT. TCS > 10 KT		
0	84	6	(138)	81	13	(144)	29	46	(140)	DX
		4	(106)		-41	(115)		-62	(107)	DY
24	78	-17	(282)	49	49	(236)	14	41	(315)	DX
		-77	(209)		-72	(201)		-16	(152)	DY
48	67	11	(504)	34	-40	(464)	8	-192	(583)	DX
		-145	(383)		-72	(306)		-6	(193)	DY
72	53	35	(714)	22	-59	(682)	5	-370	(737)	DX
		-132	(593)		6	(354)		90	(225)	DY
96	38	48	(938)	20	29	(1091)	3	-236	(674)	DX
		-22	(581)		170	(593)		145	(206)	DY
120	31	333	(1225)	13	-191	(1494)	1	96	(*****)	DX
		179	(689)		169	(570)		-67	(*****)	DY

Standard deviations are given in the parentheses.
All errors are measured in KM.

APPENDIX A

Diagrammatic Explanation of Forecast Errors



OB1-3 : Observed positions
FC : Forecast position verifying against observation OB2
DPE : Direct positional error
DX : Error in the East-West direction
DY : Error in the North-South direction
AT : Error in the Along Track direction
CT : Error in the Cross Track direction

All errors are measured in kilometres

Sign Conventions

DPE values are always positive.
DX errors are positive if the forecast position lies eastwards of the observed position.
DY errors are positive if the forecast position lies polewards of the observed position.
AT errors are positive if the forecast position lies ahead of the observed position along the tropical cyclone track.
CT errors are positive if the forecast position lies right of the observed track in the northern hemisphere and left of the observed track in the southern hemisphere.